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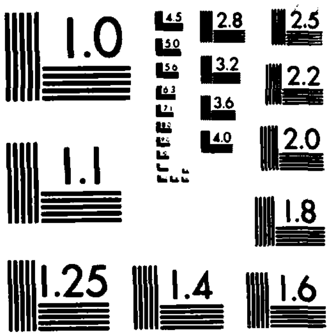

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AIR DEPLOYED ACOUSTIC MOORING ARRAY DEVELOPMENT

Leonard Davis
David Dillon
Larry Kahn

EG&G WASHINGTON ANALYTICAL SERVICES CENTER, INC.
2150 FIELDS ROAD
ROCKVILLE, MD 20850

MAY 1983

FINAL REPORT

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This report documents the technological accomplishments in the Air Deployed Acoustic Mooring (ADAM) array development program during 1982. Technology is being developed for deploying acoustic sensors from an aircraft in the open oceans of the world. The continuation of the ADAM technology development is detailed.

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ACKNOWLEDGEMENT

The support of Woods Hole Oceanographic Institution and especially Mr. Robert Walden and his staff in the procurement, packaging and testing of the array cable and mooring line is acknowledged with gratitude.

SECTION II

INTRODUCTION

Since early 1977, a group of investigators have been developing an Air Deployed Oceanographic Mooring (ADOM)* for gathering scientific data. ADOM is essentially an automatically moored two-stage instrumented mooring (Figure 1). The electronics and power supply are located in the subsurface buoy. The sensor array forms the upper portion of the mooring line immediately below the subsurface buoy. It is presently able to measure temperature and depth. Data is retrieved from a transmitter in the surface buoy, through the LES-9 satellite (Figure 2).

Early in the development of ADOM, it was anticipated that other sensors would be integrated into the ADOM platform to meet various scientific requirements as they developed. Based on the Naval Ocean Research and Development Activity's (NORDA) interest in measuring environment acoustics at remote sites, a 2 1/2 year, three-phase program was developed to integrate acoustic sensors into the ADOM platform. This new program uses the acronym ADAM (Air Deployed Acoustic Mooring).

This report documents only the initial phase of the ADAM program performed by EG&G Washington Analytical Services Center, Inc. The analyses and tests required to develop an ADAM compatible hydrophone/cable assembly are described in the following sections of this report.

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* References are listed on page 41.

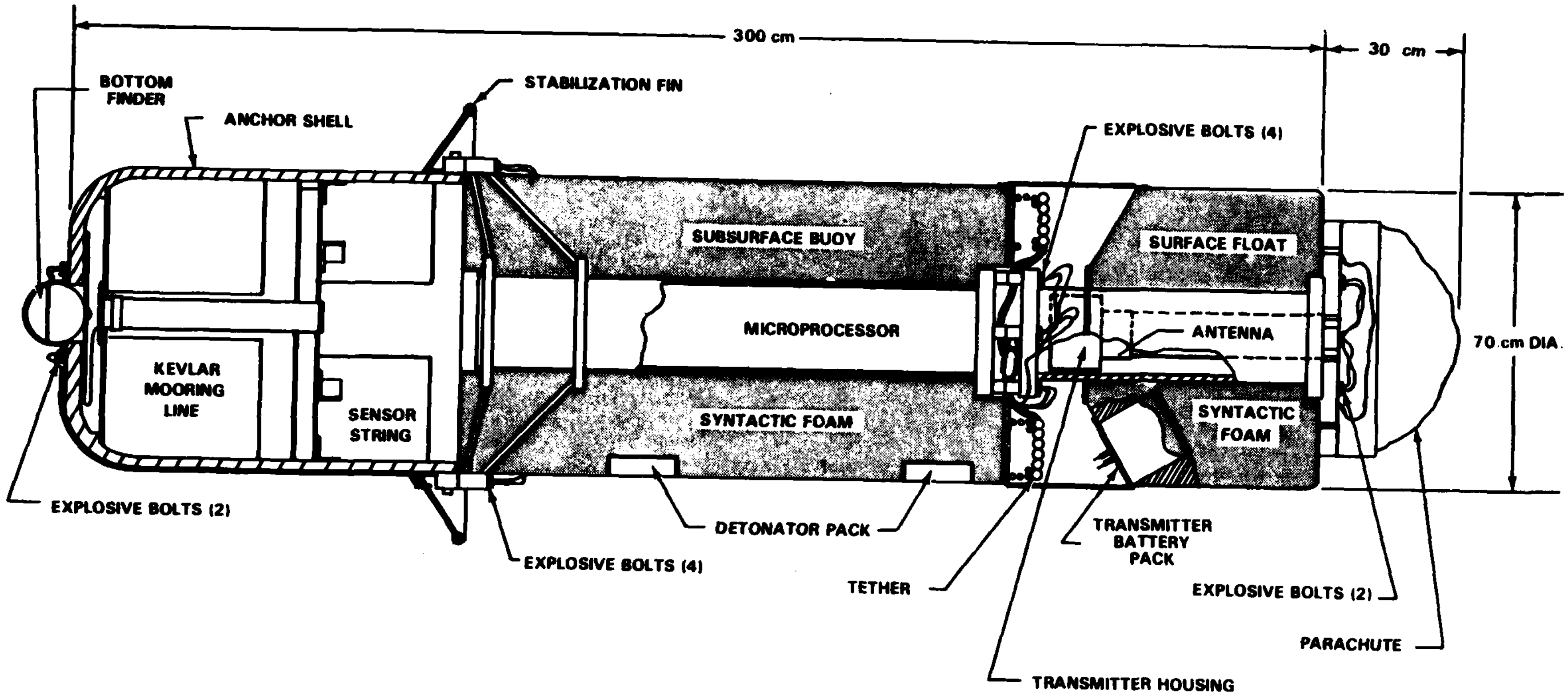

Figure 1. ADOM Sectional View

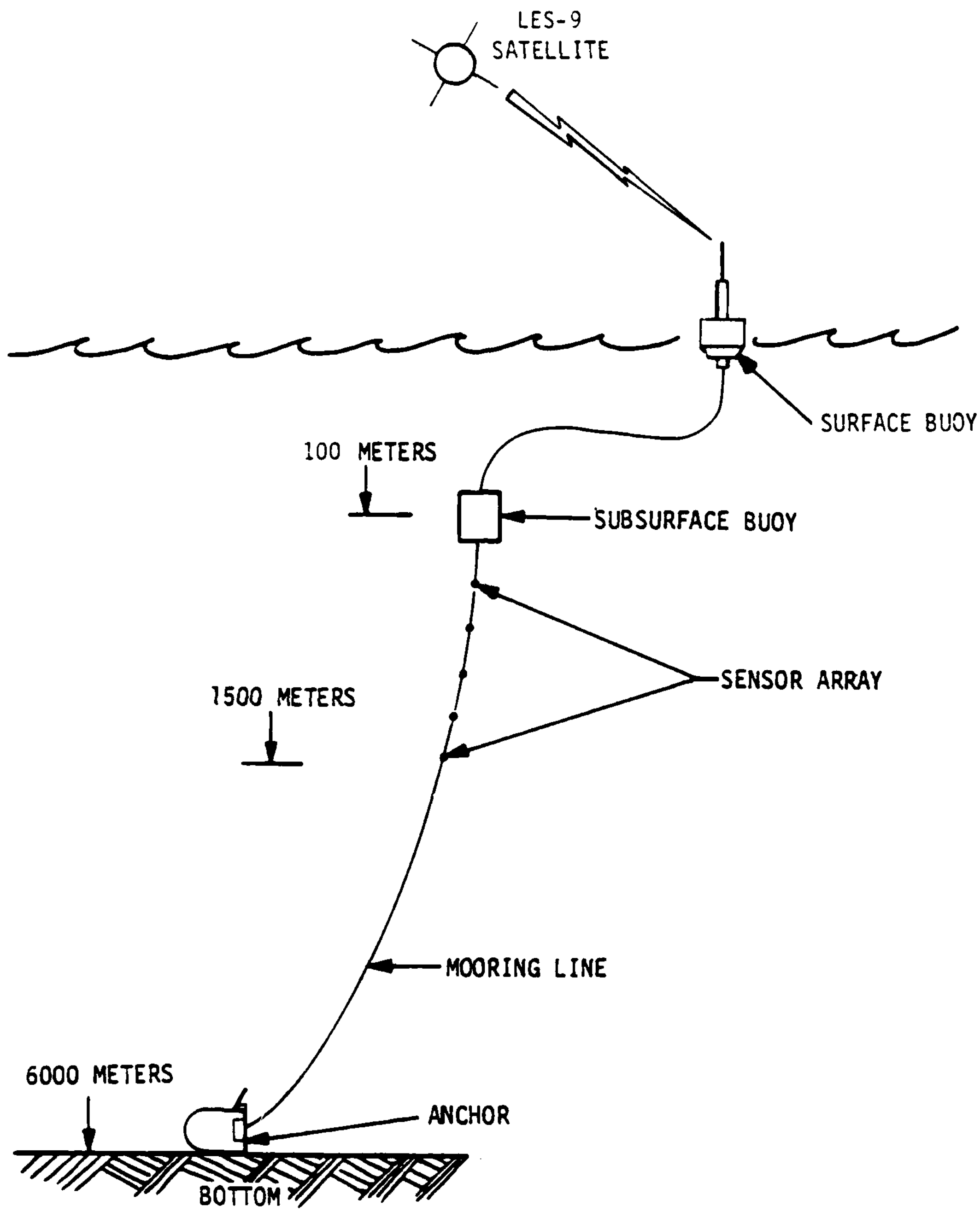

Figure 2. ADOM Deployed

SECTION III

ANALYSES

3.0 General

The initial phase of the design and fabrication of an Air Deployed Acoustic Mooring (ADAM) compatible hydrophone/cable assembly began with a dynamic analysis of the buoy system to describe the motions of selected locations on the sensor array in various sea states and water depths. In addition, an analytical model of the sensor array was prepared to describe the strumming effect for different array cable end conditions.

3.1 Dynamic Motion Analysis of RAMS Mooring Configurations

The NDBO cable dynamics computer program[2] was used to perform a dynamic analysis of the Remote Acoustic Measurement System (RAMS). Ideally, the tethering system would completely isolate the array from wave action. Computer models estimate its motion in Sea State 3 to be about an inch.

Figure 3 shows the static configuration for the RAMS cable system for various percentages of the operational current. Only the 100% operation current (.6 m/s at surface) was analyzed with the computer program. (At lower current speeds the upper tether is too slack for efficient modeling with this program.) The current produced by a Sea State 3 wind is 30 to 40 percent of the operational surface current and decreases nearly to zero at a depth of 50 m.

The NDBO computer program computes the cable dynamic velocities and tensions due to unit amplitude waves approaching at discrete frequencies. Cable displacements are computed by dividing the velocity by the frequency.

For statistical motion analysis, two curves, the wave energy density and response amplitude operator (RAO) function, are required. The square root of the area under the curve defined by the wave energy density times $(RAO)^2$ represents an average (RMS) value of the response of a point on the mooring to wave excitation. Multiplying this value by suitable constant ratios gives the 1/3 highest responses (significant response), 1/10 highest or other desired extremes.

For computer analysis, the sea wave spectrum is divided into a number of discrete frequencies and the integration is performed numerically. In this

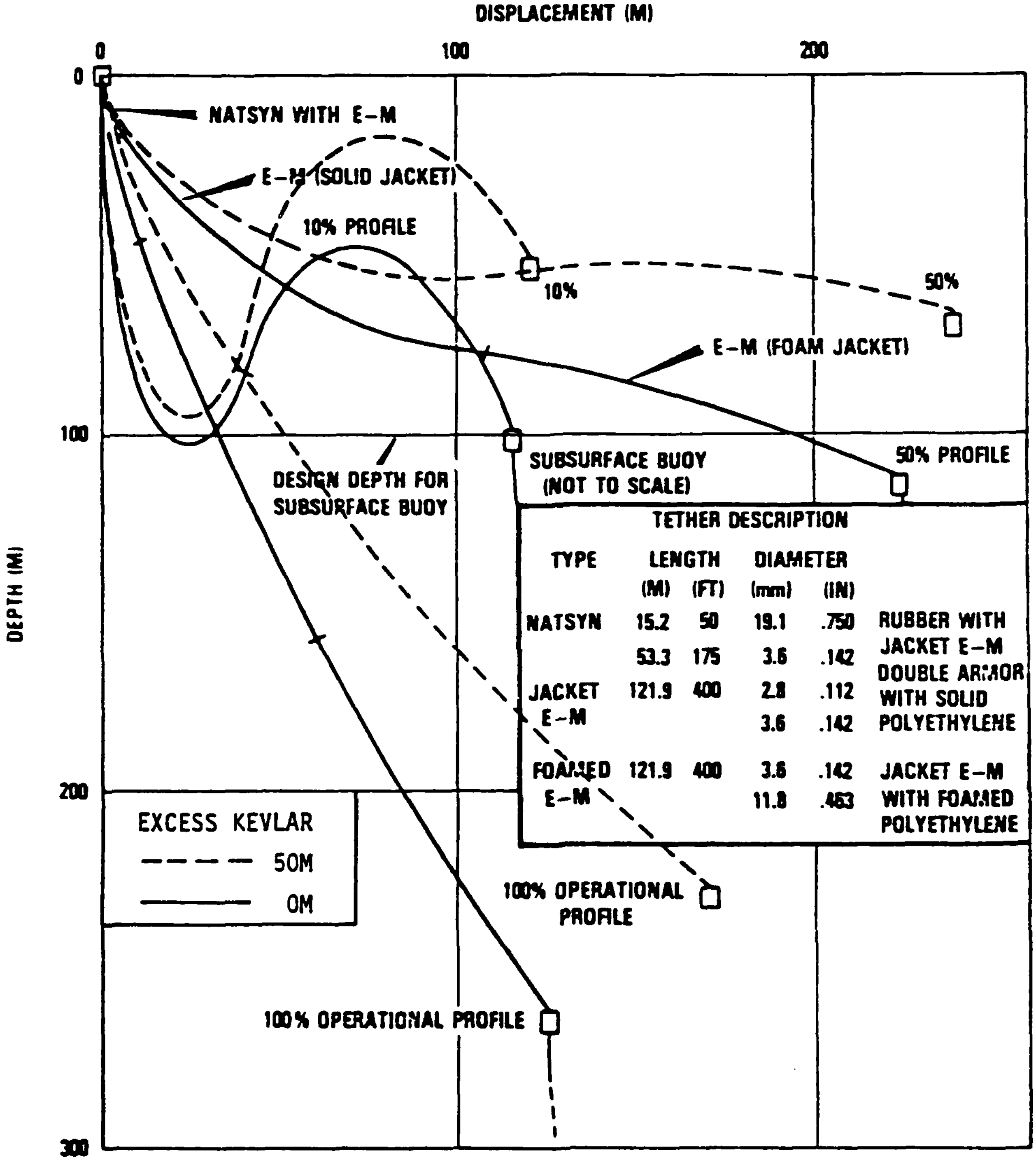

Figure 3. Static Configurations of Upper Tether

example, eight frequencies were used, ranging from .08 to .4 Hz. This range covers sea states 0 - 6. Eight frequencies were judged sufficient for a reasonably accurate prediction.

Table 1 shows the input parameters to the NDBO model a typical case: water depth 6000 m and nominal array depth 100 m. Other cases are identical except for varying the cable length to suit the water depth. Figures 4 through 9 show the array motion transfer functions for three mooring depths corresponding to the operational current case. Each graph contains two curves, one for a 100 m nominal subsurface buoy depth and one for 200 m.

At 100 m, water motion due to Sea State 3 waves is nil. Therefore, subsurface buoy motion is caused primarily by tension variations that propagate down the tether from the surface buoy. Average tether tensions were lower for the 200 m case than for 100 m. This is due to the longer surface buoy tether required and the added NATSYN action in the tether.

In most cases, the response increases with decreasing frequency, indicating the very low fundamental frequency of the system. The exception is the 2000 m water depth case, where the shorter cable length has moved a major natural frequency into the frequency range expected for wave excitation.

Figures 10 through 15 show the wave energy density spectrum for three sea state 3 conditions and Figure 13 shows a Sea State 6 for comparison. As the wave height increases or the peak frequency decreases, the spectrum becomes more narrow-banded. For these cases, simply multiplying the transfer function at the peak frequency by the wave amplitudes yields a good approximation of the integrated response. In cases where the spectrum is broad-banded the simpler method may underpredict the response since there is significant energy at off-peak frequencies. Figures 14 and 15 show examples of two integrated response spectra.

Tables 2 and 3 contain the array significant motions for sea states 3 and 6. Maximum horizontal motions occurred at the subsurface buoy (top of the array) for all cases. The location of the point on the array having the largest vertical response to wave excitation varied with the water depth. Vertical motion was greatest at the array top for 2000 m water depth, near the array center at 4000 m and at the array bottom in 6000 m.

TABLE 1. COMPUTER PROGRAM INPUT

buoy characteristics
(all in foot-pound-second units)

length=	2.330	weight=	232.000			
l.c.g.=	0.	v.c.g.=	1.100	bradius=	.500	
x-cable=	0.	z-cable=	0.	max.draft=	2.540	
cur.c(d)=	.70000	cur.c(l)=	0.	cur.c(a)=	0.	
wind.c(d)=	0.	wind.c(l)=	0.	wind.area=	0.	wind.arm=

* * * * * * s p a r type * * * * *

section		height to top	a	b
1	cylinder	.67	.4165	0.
2	conical	1.04	3.3250	.5415
3	cylinder	2.54	1.1650	0.

add.mass.coeff. = .70000

table of cable properties

cable	length	wt in air	wt in water	diameter	area	elasticity	break tension	w0	taul	cn
	ft	lbs/ft	lbs/ft	in	sq.in.	lbs/sq in	lbs	lbs	sec	
1	50.00	.25670	.06040	.750	.442	150.0	1150.0	0.	0.	1.790
2	400.00	.02400	.01700	.142	.016	3621000.0	1100.0	0.	0.	1.800
3	400.00	.06640	-.00850	.463	.169	340200.0	1100.0	0.	0.	1.800
4	4900.00	.04550	.03510	.173	.024	5820000.0	2370.0	0.	0.	1.800
5	14350.00	.01360	.00050	.194	.030	2242000.0	3200.0	0.	0.	1.800

table of attachment properties

attachment	distance from buoy	wt in water	drag constant	virtual mass(normal)	virtual mass(t
	feet	lbs	slugs/ft	slugs	slugs
1	850.00	-546.000	12.000	55.000	37.000

physical data

depth of water=19685.00 feet   wind velocity= 0. knots   mass density of water= 1.9905 slugs/cu.ft.

table of current properties

depth	current velocity	current gradient
ft	knots	knots/ft
0.	1.200	.001
164.00	.960	.001
492.00	.686	.000
1148.00	.436	.000
1640.00	.343	.000
3280.00	.200	.000
19685.00	.080	.000

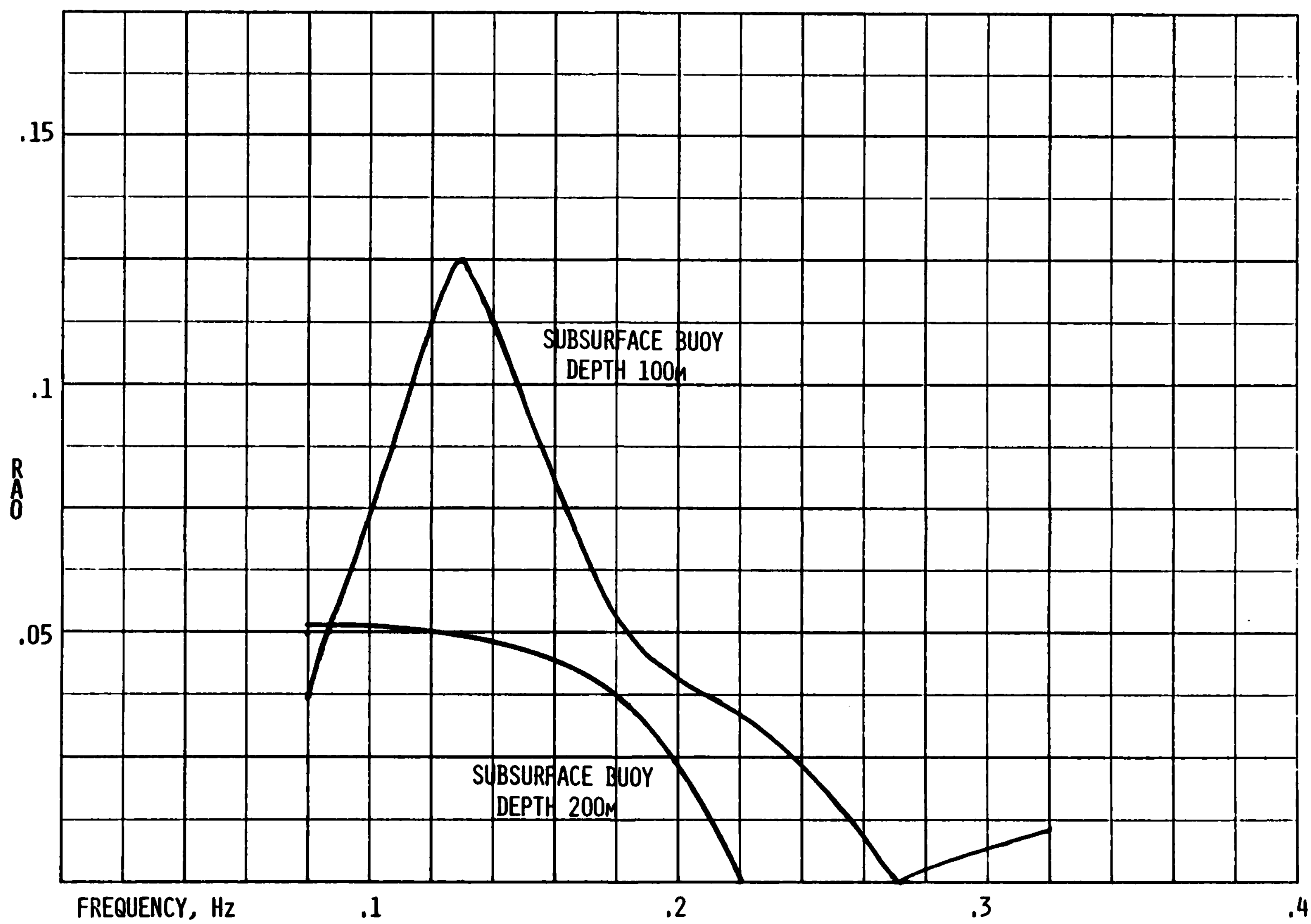

Figure 4. Array Horizontal Response Transfer Function for 2000 m Water Depth

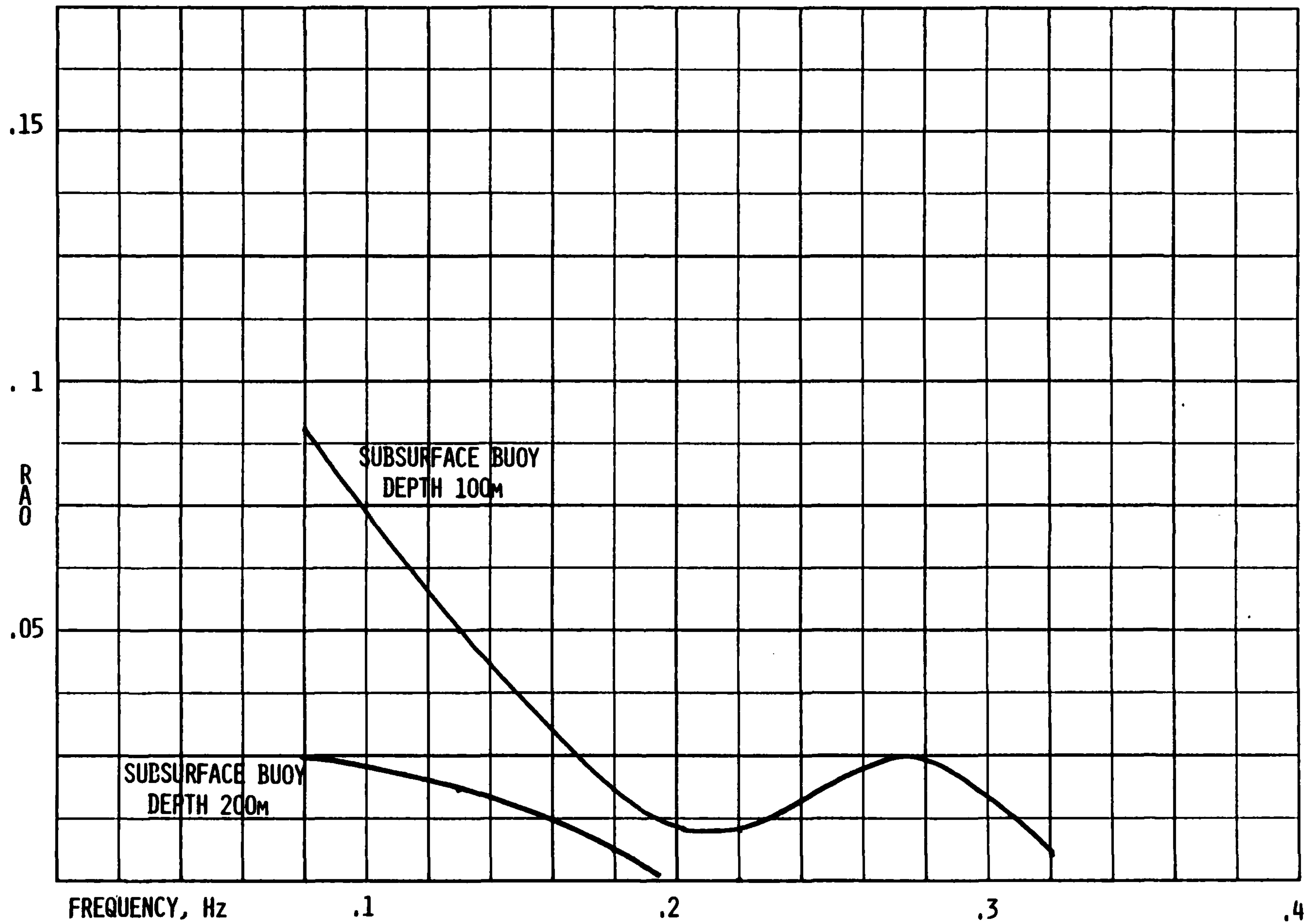

Figure 5. Array Vertical Response Transfer Function for 2000 m Water Depth

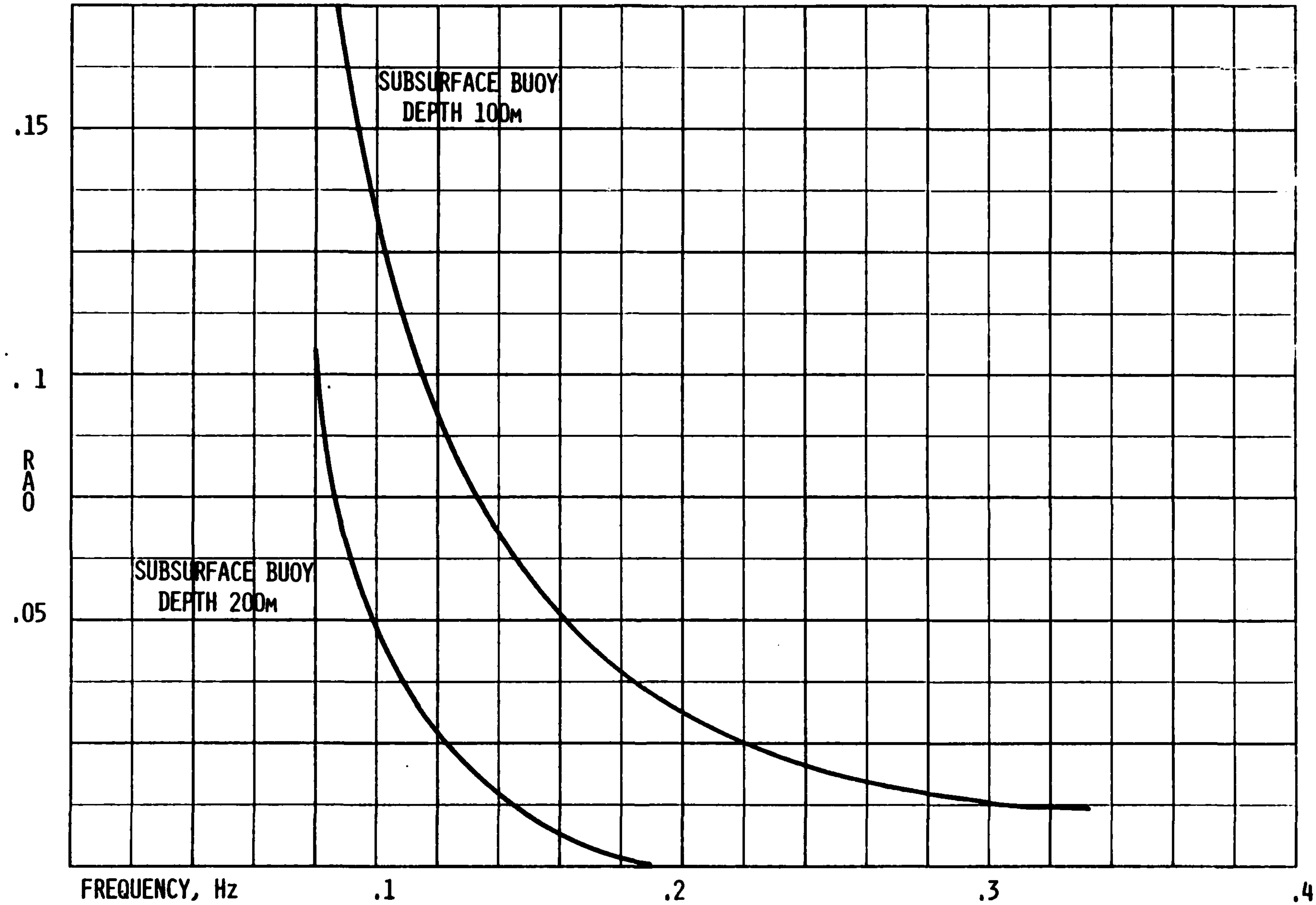

Figure 6. Array Horizontal Response Transfer Function for 4000 m Water Depth

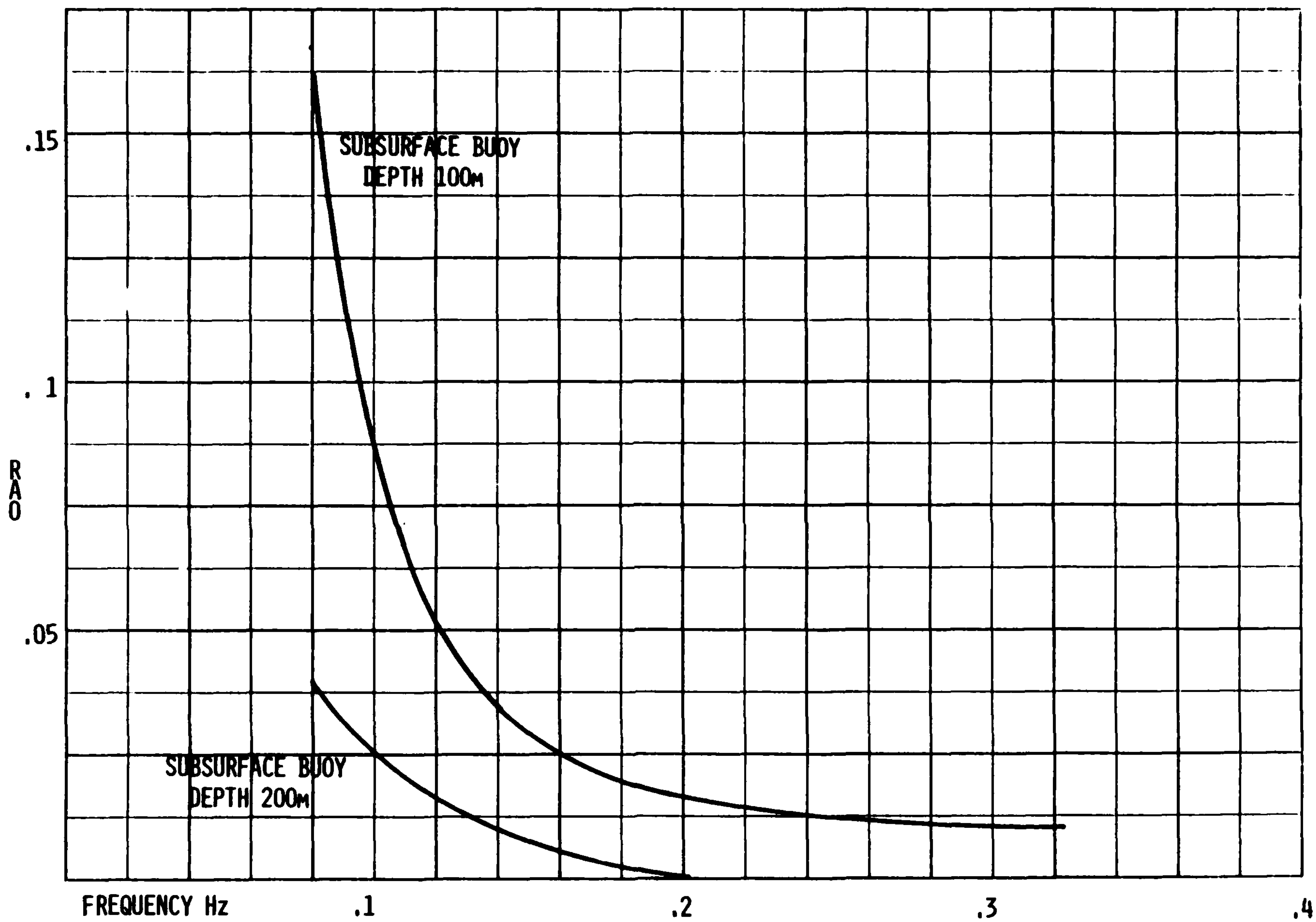

Figure 7. Array Vertical Response Transfer Function for 4000 m Water Depth

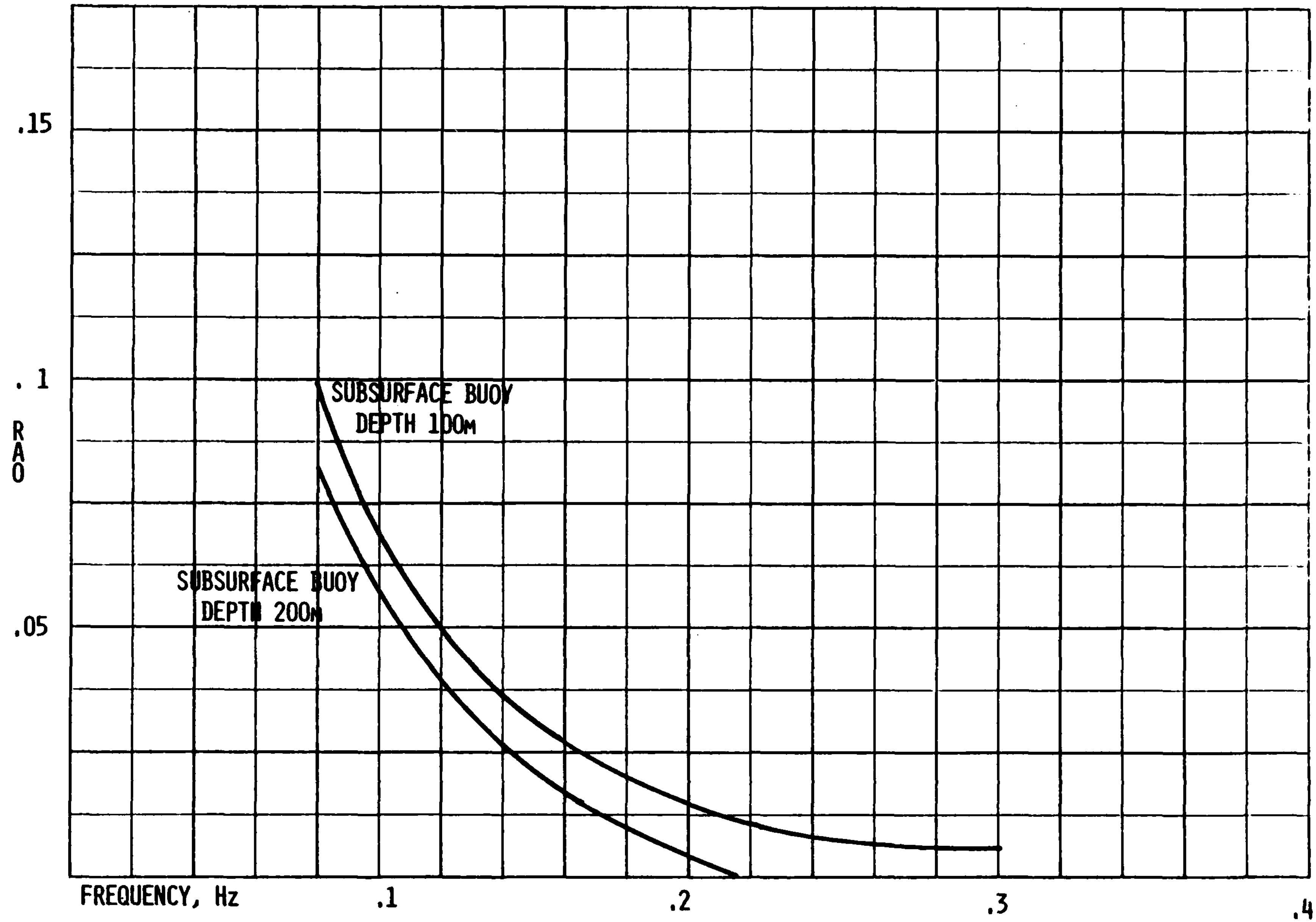

Figure 8. Array Horizontal Response Transfer Function for 6000 m Water Depth

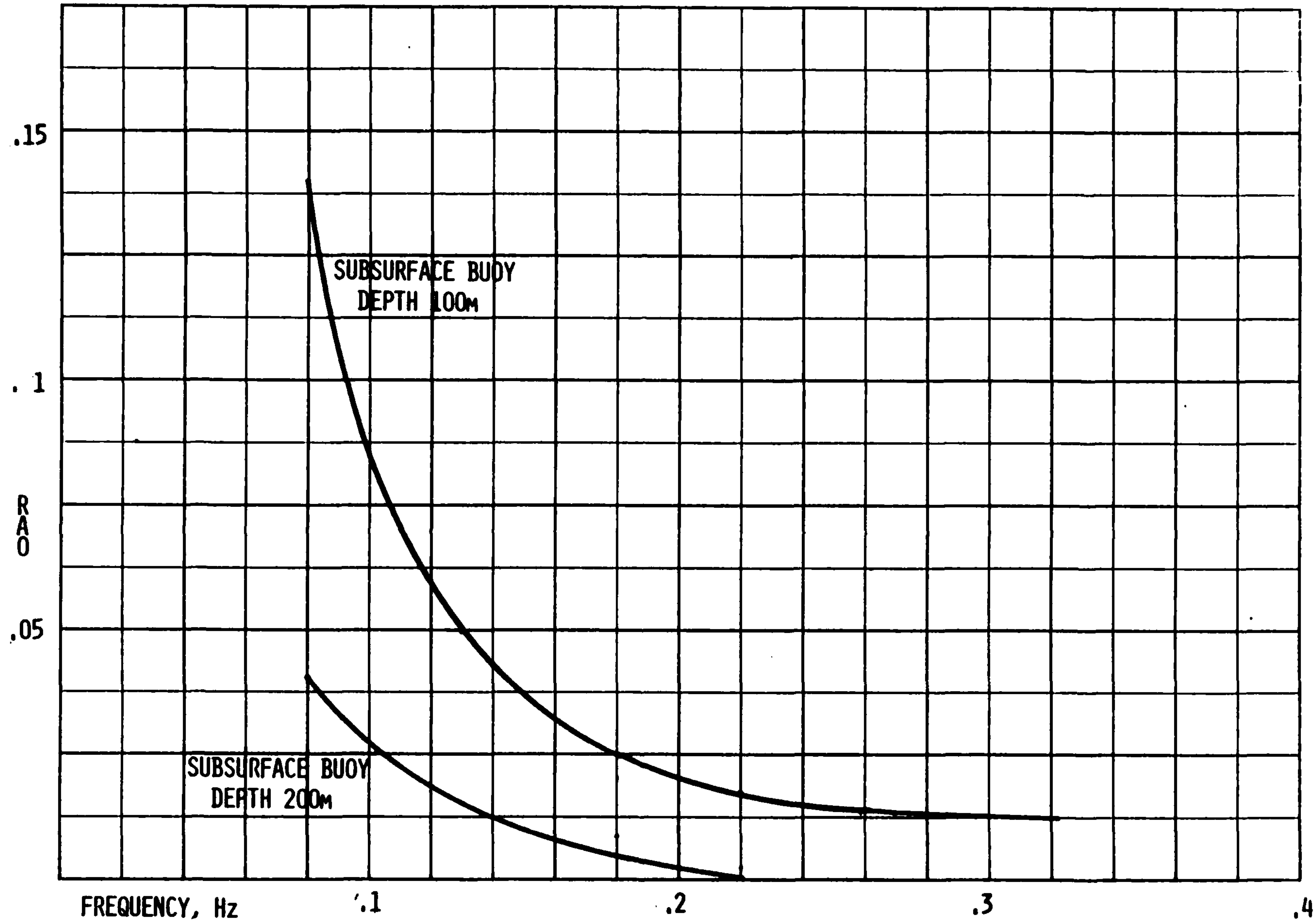

Figure 9. Array Vertical Response Transfer Function for 6000 m Water Depth

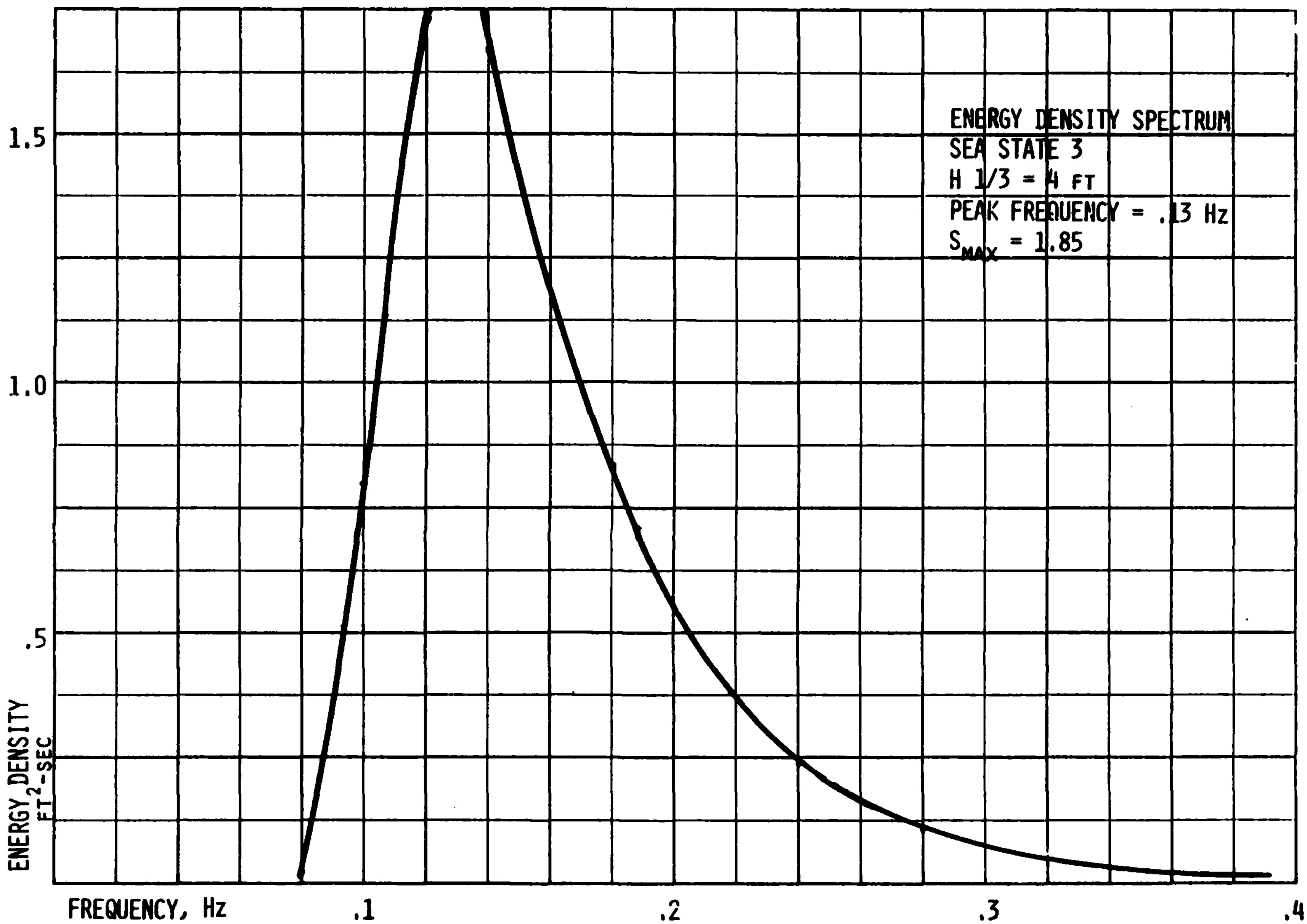

Figure 10. Wave Energy Density Spectrum (Peak Frequency = 0.130 Hz)

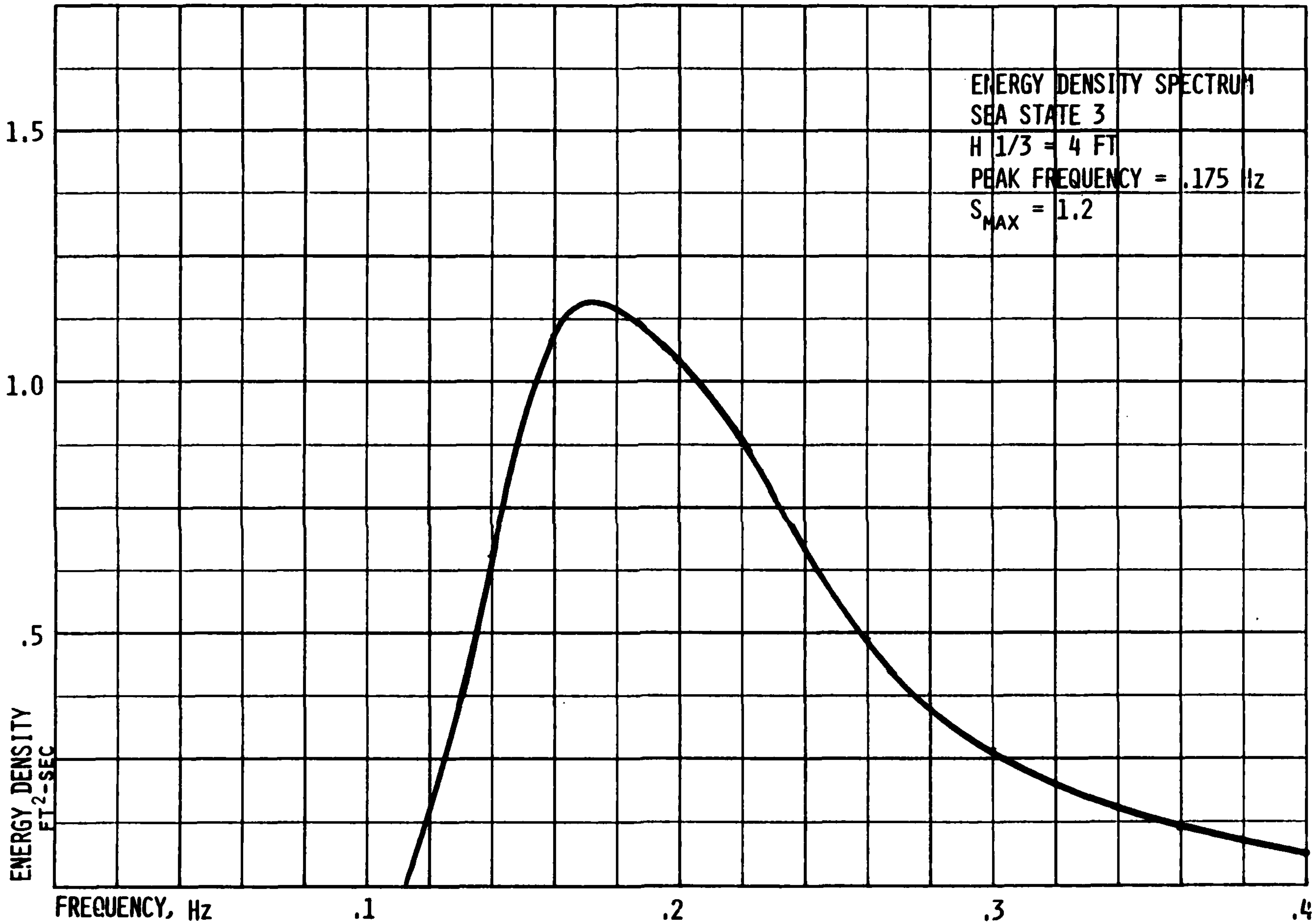

Figure 11. Wave Energy Density Spectrum (Peak Frequency = 0.175 Hz)

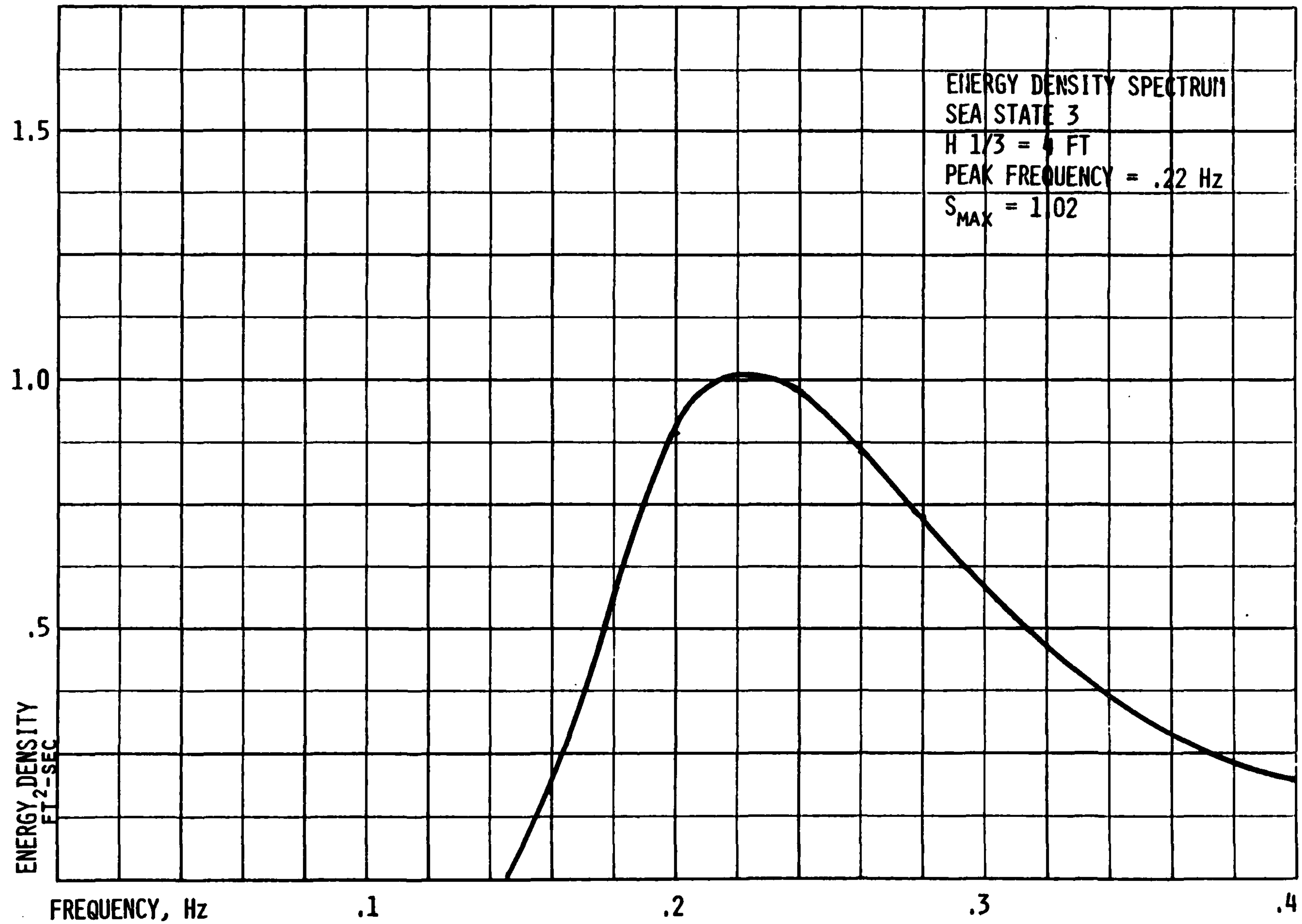

Figure 12. Wave Energy Density Spectrum (Peak Frequency = 0.220 Hz)

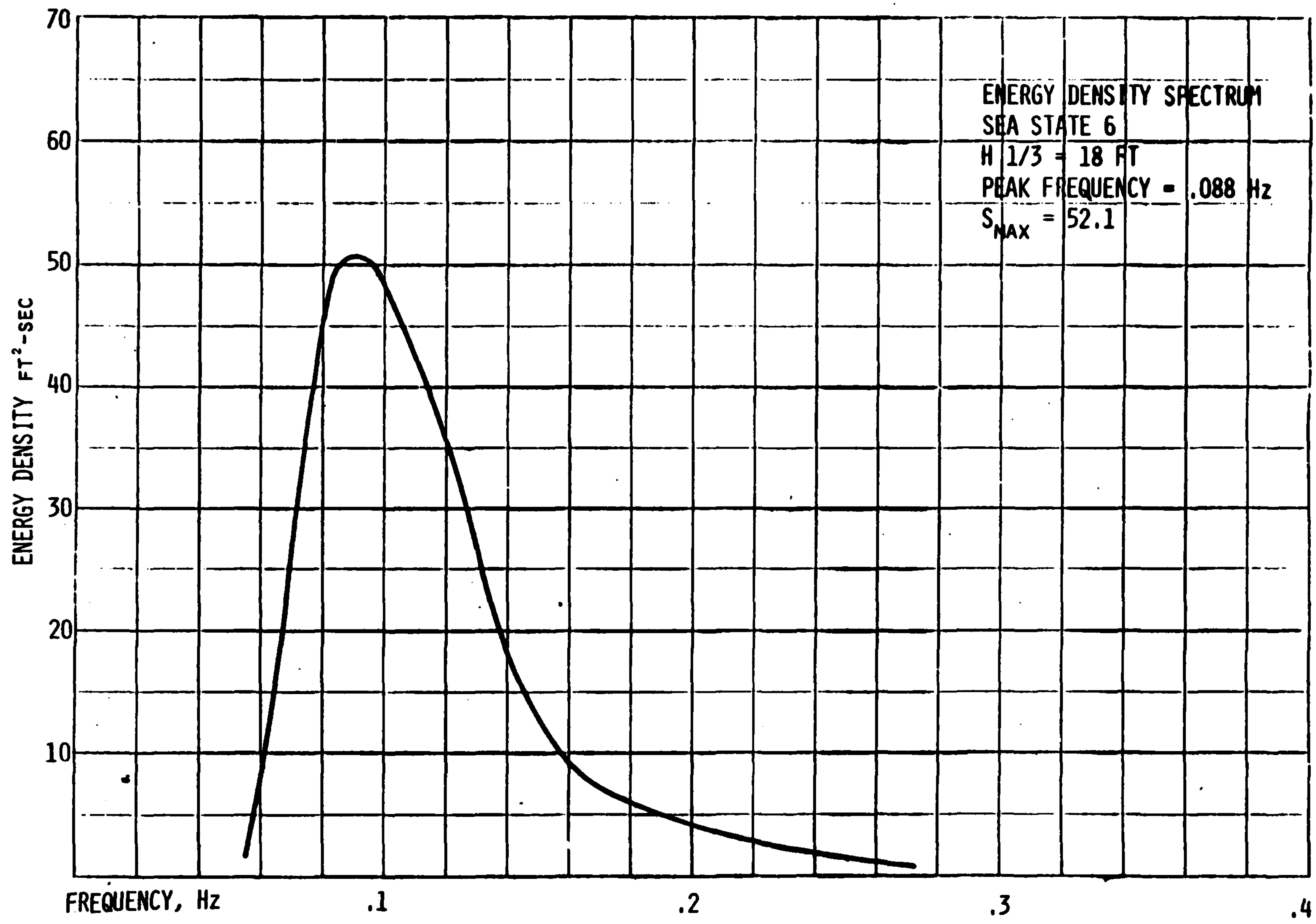

Figure 13. Wave Spectrum (Sea State 6, Peak Frequency = 0.088 Hz)

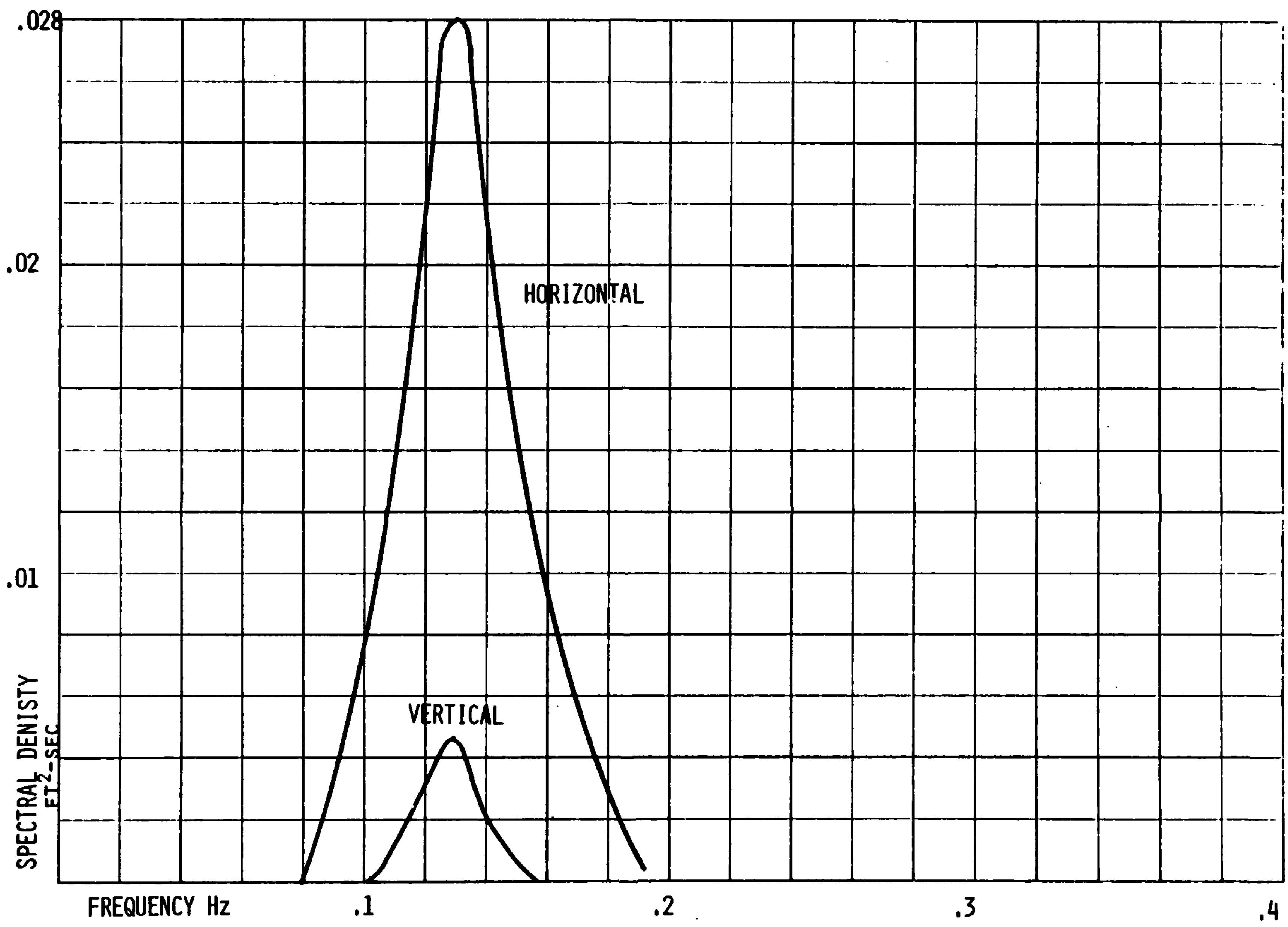

Figure 14. Response Spectral Density of Array Motion for Sea State 3,
Water Depth = 2000 m

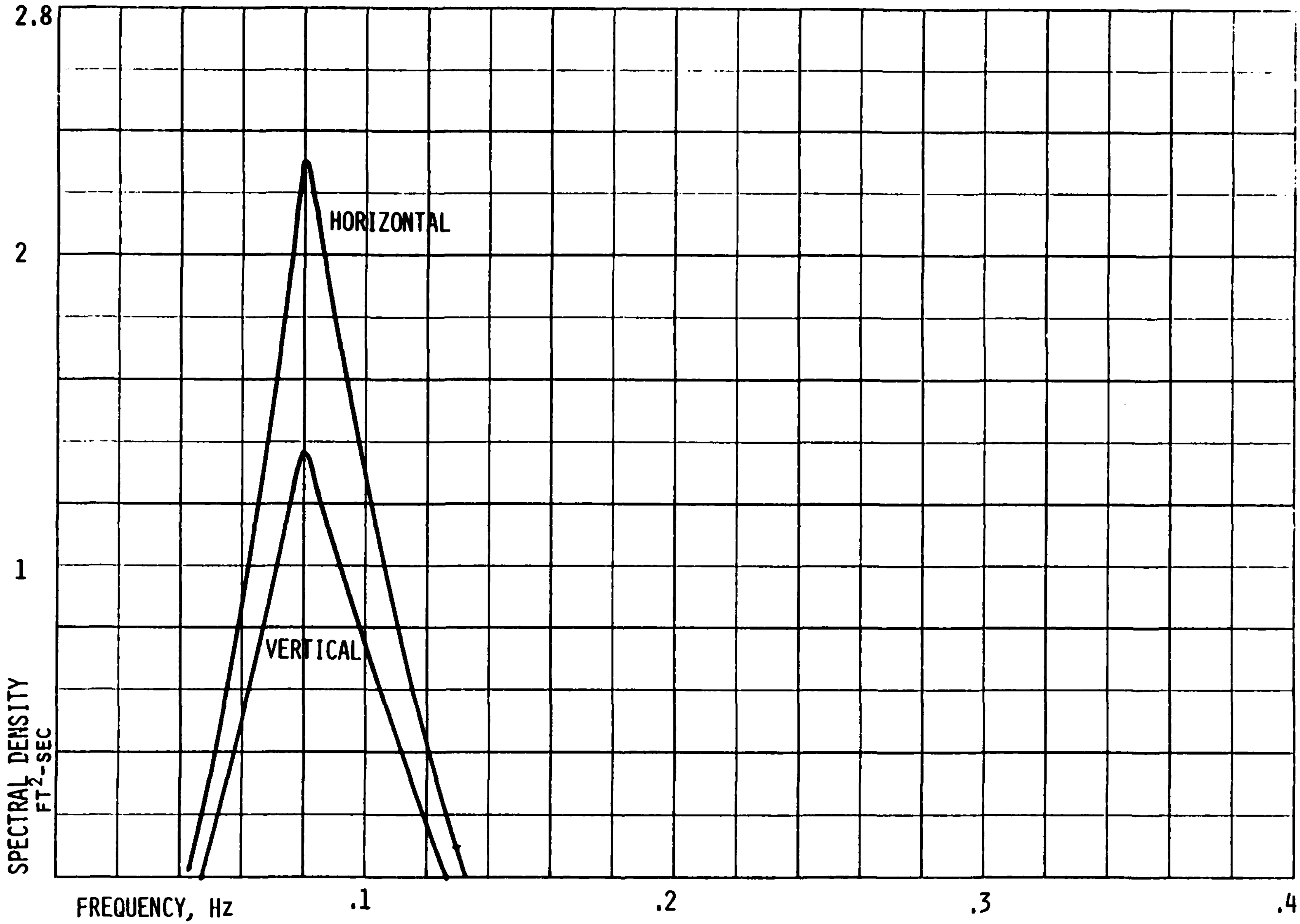

Figure 15. Response Spectral Density of Array Motion in Sea State 6, Water Depth = 4000 m

TABLE 2. ARRAY SIGNIFICANT MOTIONS

SEA STATE 3, $H_{1/3}$ = 4 FT, PEAK FREQUENCY = .13 Hz

	WATER DEPTH		
	2000m	4000m	6000m
NOMINAL SUBSURFACE BUOY DEPTH - 100m			
HORIZONTAL	7.9cm	5.1cm	2.8cm
VERTICAL	3.2cm	3.6cm	3.6cm
NOMINAL SUBSURFACE BUOY DEPTH - 200m			
HORIZONTAL	3.3cm	2.8cm	2.4cm
VERTICAL	1.1cm	1.1cm	1.1cm

TABLE 3. ARRAY SIGNIFICANT MOTIONS

SEA STATE 6, $H_{1/3}$ = 18 FT, PEAK FREQUENCY = .09 Hz

	WATER DEPTH		
	2000m	4000m	6000m
NOMINAL SUBSURFACE BUOY DEPTH - 100m			
HORIZONTAL	25.9cm	58.2cm	26.7cm
VERTICAL	21.8cm	44.7cm	42.4cm
NOMINAL SUBSURFACE BUOY DEPTH - 200m			
HORIZONTAL	15.2cm	29.2cm	22.6cm
VERTICAL	6.9cm	10.7cm	10.7cm

The model predicts that lowering the subsurface buoy to 200 m greatly reduces the array motions, and increasing the length of the surface tether also reduces these motions. For the various Sea State 3 and operational current cases analyzed, the lowest array motions were about one inch horizontal motion and one-half inch vertical motion.

3.2 Sensor Array Vibration Amplitudes and Accelerations

The mooring lines may "strum" in the ocean currents. The strumming is often at acoustic frequencies. The array is effectively buffered from strumming of the upper tether by the mass of the subsurface buoy. Excitation of the array by the strumming of its own cable can be inhibited with appropriate cable fairing. Fairing more than a few hundred feet of the mooring line below the array is not practical because it exceeds the storage volume available in the anchor and complicates the deployment mechanism. An analytical study was performed in order to estimate whether strumming of the deep cable would significantly affect the array and to identify appropriate mitigation measures, if need be.

A simple analytical model was formulated to investigate the response of the sensor array to a forcing function applied at its lower end. The model was that of an elastic material in a longitudinal vibration mode with a proportional tangential drag force but no material damping. The longitudinal vibration equations for a cable are readily available and formed the basis of the model.

Two end conditions were tested, one in which the end was free and one in which the end was attached to a one slug spherical mass.

The forcing functions themselves were estimated from strumming effects of the mooring cable below the array. Strum amplitudes were estimated using the method described in Reference 3 for the range of current speeds expected below the array. The tension fluctuations were estimated from the cable geometry and material elasticity. For a given strum amplitude, the Kevlar® ends were held fixed and the tension was computed based on the cable strain due to the strum The tension fluctuation frequency is twice that of the strumming frequency. The amplitude of tension fluctuations at junction between the array and mooring line ranged from near zero to a maximum of 4.5 N for a 0.1 m/s current (Table 4).

TABLE 4. KEVLAR STRUMMING CHARACTERISTICS

Assumptions

1. Single mode vibration.
2. Strouhal number = .21
3. Strum amplitudes determined from NRL Memorandum Report 3383.
4. Ends assumed fixed for tension calculations.
5. Currents range from 0 to .1 m/s.
6. Average tension = 1783.2 N, EA = 67000.

Current Speed (m/s)	Strum Frequency (Hz)	Tension Fluctuations at array - Kevlar junction (N)
.01	.44	.013
.02	.88	.137
.03	1.32	.451
.04	1.75	1.032
.05	2.19	1.922
.06	2.63	3.119
.07	3.07	4.679
.08	3.51	6.690
.09	3.95	9.053
.10	4.39	11.859

NOTE: Tension fluctuation frequency = 2 x strum frequency

Applying these conditions to the bottom end of the sensor array without mitigation yielded accelerations up to about 0.5 g's (Table 5). Table 6 shows comparable results when a mass is interposed between the array and mooring line. The mass acts to reflect tension waves back into the mooring line. The model predicts that the worst accelerations were reduced by about three-fourths, to 0.13 g's, for a 14.5 kg mass. Adding weight to the array bottom is a simple, effective method to reduce the vibration load.

TABLE 5. ARRAY VIBRATION AMPLITUDES AND ACCELERATIONS

1. No material damping.
2. Array length = 1493 m
3. Free End

Tension Frequency	Current Speed (m/s)	Position of Max. Amplitude 0 = Subsurface Buoy (m)	Fluctuations Amplitude (cm)	Acceleration (G's)
1	.01	750	.0003	.0001
2	.02	373	.0104	.0017
3	.03	1269	.0173	.0063
4	.04	1344	.028	.018
5	.05	149	.043	.044
6	.06	373	.061	.087
7	.07	1195	.079	.156
8	.08	1045	.091	.243
9	.09	1269	.117	.377
10	.1	75	.119	.480

TABLE 6. ARRAY VIBRATION AMPLITUDES AND ACCELERATIONS

1. No material damping.
2. One 14.6 kg sphere at array bottom.
3. Tangential hydrodynamic damping C_t = .01
4. Array Length = 1493 m

Tension Frequency	Current Speed (m/s)	Position of Max. Amplitude 0 = Subsurface Buoy (m)	Fluctuations Amplitude (cm)	Acceleration (G's)
1	.01	745	.0003	.0001
2	.02	1120	.009	.0015
3	.03	1269	.014	.0005
4	.04	1344	.002	.013
5	.05	149	.025	.026
6	.06	896	.030	.044
7	.07	1195	.033	.068
8	.08	1419	.036	.090
9	.09	1269	.036	.120
10	.10	75	.030	.128

SECTION IV

ARRAY DEVELOPMENT

4.0 General

Array development was marked by the identification, procurement and testing of a new kink-resistant array cable, the design and fabrication of the hydrophone housing; design and fabrication of a tuned spar buoy for the hydrophone drift test platform; and a test to verify that electrical conductors embedded in a Kevlar strength member are not damaged during the mooring line lock-up sequence.

4.1 Array Cable

The ADAM program requires that the array cable must be 1200 m long, store within the anchor and automatically deploy without fouling. The storage basket in the anchor is substantially too small to hold a 1200 m array packed in the normal, figure-8 pattern. Other patterns pack the array more densely. However, those patterns did not deploy reliably in tests performed during the prior ADOM program. The main problem was the formation of kinks. Accordingly, a new cable, using a different construction technique was procurred for test and evaluation. The cable is kink-resistant using double caged armor providing a torque balanced construction. The physical properties of the cable are listed in Table 7.

The cable underwent three initial tests. The first was a simple rotational test to evaluate the torsional characteristics of the cable. A 6.6 m length of array cable was suspended from a bridgecrane with a 260.8 kg anchor attached to the lower end and lifted above the floor. The number of revolutions were counted and the direction of rotation observed. Between each lift the anchor was lowered to the floor and the cable allowed to relax. The results of the test are given in Table 8.

A second test was the verification of the cable breaking strength. Four one meter test samples were prepared with a poured plastic cable socket attached at each end. The armor wires of test samples 1 and 2 were cleaned in solvent and placed in the cable socket and potted with a poured plastic compound. On test samples 3 and 4 the armor wires were cleaned in solvent, sandblasted and then potted the same as 1 and 2. All four samples were then

TABLE 7. ARRAY CABLE CHARACTERISTICS

Physical Properties:

Cable Diameter: 0.538 cm

Armor: Kink Resistant, Double-Caged and Torque Balanced

Center Conductor: No. 18 AWG Stranded Copper Wire with Low Density Polyethylene insulation

Jacket: Black Surlyn Sheath .381 mm thick

Electrical Properties:

Nominal DC Resistance at 20°C: 6.51 ohms/k'

Mechanical Properties:

Breaking Strength: 8897 N

Mass in Air: 22.7 kg/305 m

Mass in Sea Water: 15.9 kg/305 m

TABLE 8. ARRAY CABLE TORQUE CHARACTERISTICS

Test Lift* 1st Lift	Total Revolutions	Direction	Rev. per Foot
1	1 1/16	CW	.049
2	1/8	CW	.006

* Sample did not kink when relaxed between lift 1 and 2.

pulled to destruction in a Universal Test machine. The results of this test are given in Table 9.

A third test was conducted from a simulated anchor in order to demonstrate kink resistant properties of the cable while achieving maximum packing density. A length of about 430 m was used in this test - substantial, but not the full-scale 1200 m. The cable was packed using a "one under-one over" configuration. Then a coat of deploymerized rubber (DPR) was brushed on to insure that cable layers stayed securely in place until pulled from the anchor basket. Cable packing was easy and without torque build up that prevents coils from laying flat. The cable was pulled straight up from the basket. Pull-out tension was less than one pound. Not more than two turns stuck together and kinking did not occur. No other problems were experienced.

The 430 m length of cable was again repacked in the anchor basket using the one under-one over configuration with a coat of DPR brushed on each layer as in the first test. The cable basket was weighted for an at-sea drop test from the CAPE FLORIDA to simulate an aircraft deployment. The weighted basket with the new test array cable was rigged and dropped from the CAPE FLORIDA using the ship's deck handling equipment. The at-sea test was a non-instrumented, non-visual test. The only determination of a successful test was the condition of the array cable when retrieved after the test. The array cable, after retrieval was closely examined and found to be free of any tangles, kinks or any sign of these having started to form during the deployment.

4.2 Hydrophone

Hydrophones are placed in line at specified intervals along the array cable. The hydrophone, including cable termination is 16.2 cm in length and 4.1 cm in diameter and fabricated from 6061-T6 aluminum. The center section houses electronics. Transducers are spaced around the outer circumference of the cylinder. Both the electronic section and transducers are sealed against water intrusion by encapsulation in a plastic resin. The strength members of the array cable are terminated in a poured plastic socket attached to the hydrophone center sections by a bolt flange at each end. The tensile strength of the entire unit exceeds that of the array cable. The housing for the hydrophone with cable termination is shown in Figure 16.

TABLE 9. ARRAY CABLE BREAK STRENGTH TEST

Sample	Tension at Failure (N)	Armor Wire Preparation	Remarks
1	6229	Solvent Cleaned only	outer armor wires broke, inner
2	7916	Solvent Cleaned only	wires pulled from socket
3	8985	Solvent Cleaned & Sandblasted	outer and inner armor wires broke
4	8985	Solvent Cleaned & Sandblasted	at interface of socket and cable

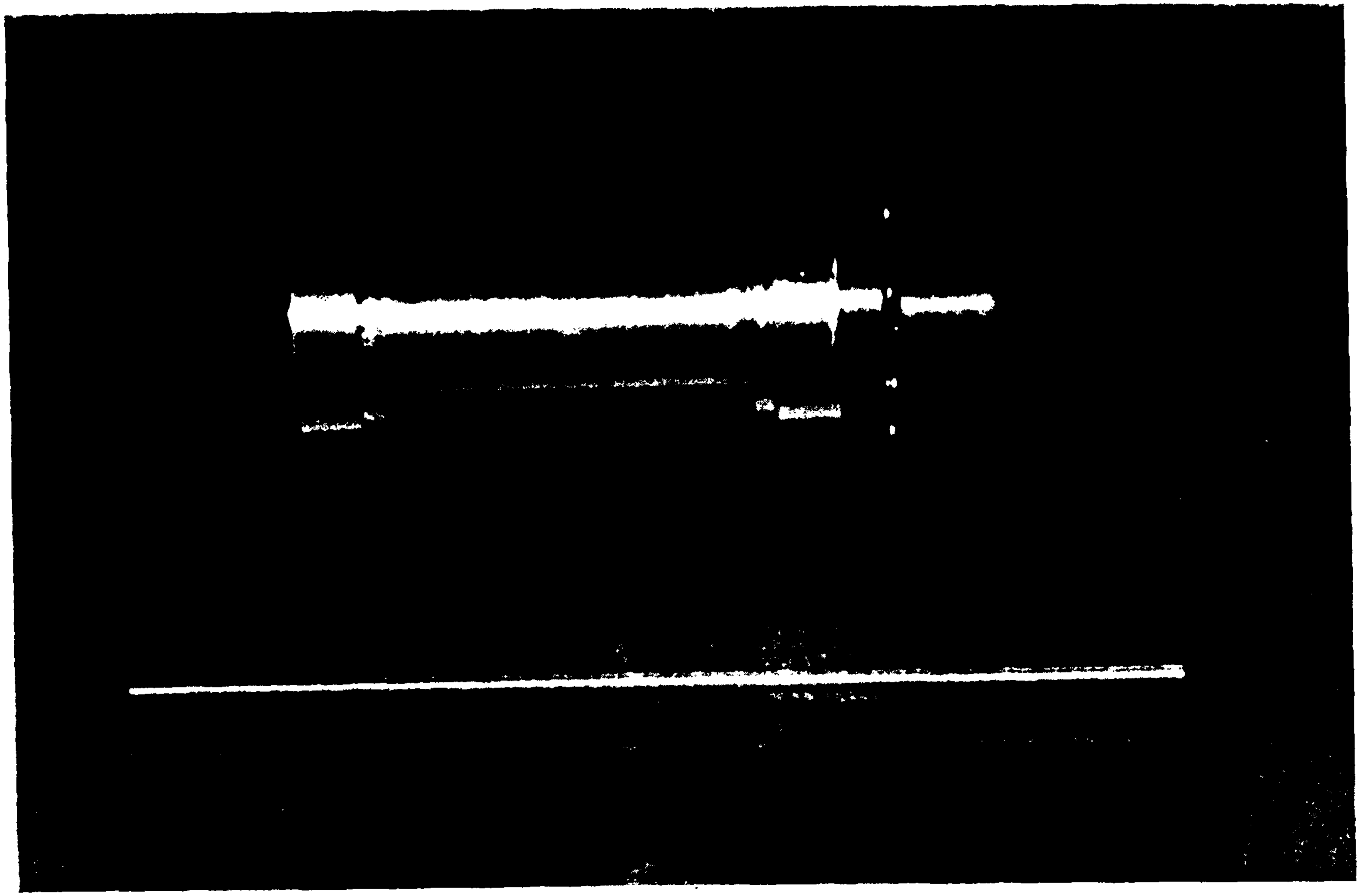

Figure 16. Housing for Hydrophone with Cable Terminations

Funding and technical assistance were provided during the calibration of the prototype hydrophone at the Naval Research Laboratory Underwater Sound Reference Detachment in Orlando, Florida. Reference 4 gives a detailed description of the design, development and calibration for the hydrophone.

4.3 Electromechanical Kevlar Line Test

The Kevlar mooring line between the sensor array and the anchor for the Air Deployed Acoustic Mooring would require electrical conductors for a bottom mounted acoustic sensor. The mooring line, when the anchor is a specified distance above the ocean floor, wraps around the anchor lock-up spindle. This abrupt loading imparts high stress in the mooring line. Tests were conducted on sample Kevlar line with integral electrical conductors to verify that damage would not occur to the conductors during the lock-up sequence. The characteristics of the Kevlar line are given in Table 10.

In the first test a length of line was tensioned between the anchor lock-up spindle and capstan head in the tension machine. Tension was applied to the E/M line in steps and after each increase the electrical continuity of the conductors was measured. Electrical continuity was interrupted at 9966 N tension when the E/M line parted against a sharp edge on the capstan. This failure occured well above the design breaking strength of the sensor array. The results of this test are listed in Table 11.

In a second test, each end of the E/M line was terminated in Spelter Sockets using a poured plastic termination. The test sample was then tensioned in steps and the electrical continuity measured after each increase in tension. There was no loss of electrical continuity until the sample failed at 13.3 kN its rated breaking strength. Table 12 gives the results of the test.

TABLE 10. ELECTROMECHANICAL KEVLAR LINE CHARACTERISTICS

Physical Properties:		
	Diameter	.76 cm
	Construction	Braided, 25 strand
	Jacket	Braided Dacron
	Electrical Core	3 Twisted Wires
Mechanical Properties:		
	Breaking Strength	13.3 kN

TABLE 11. SPINDLE LOCK-UP CONTINUITY TEST

Test Sample: .76 cm Dia. E/M Kevlar Line

Test Equipment: Universal Test Machine/Anchor Spindle

Test Description: Anchor Spindle Lock-up Test

Sample Tension, (N)	Conductivity
2227	OK
4453	OK
5336	OK
6670	OK
8004	OK
8897	OK
9789	OK
9966	OPEN - Sample parted at edge of capstan

TABLE 12. SOCKET TERMINATION CONTINUITY TEST

Test Sample: .76 cm Dia. E/M Kevlar Line

Test Equipment: Universal Test Machine

Test Description: End Termination Pull Test

Sample Tension, (N)	Conductivity
2227	OK
4453	OK
5336	OK
6670	OK
8004	OK
8897	OK
9789	OK
11123	OK
12457	OK
13349	OPEN - Sample parted

4.4 Test Platform

An in water drift test for the ADAM electronics and acoustic sensor array was originally planned. In support of this test, a small "tuned spar buoy", Figure 17, was designed and fabricated.

True spar buoys are usually difficult to handle because of the length required to obtain the necessary buoyancy. The addition of a buoyant cylinder or "drum" at the bottom end of a spar substantially reduces the overall length. Furthermore, the proportions of the cylinder may be adjusted so that a certain wave period produces no heave excitation. These buoys are often called "tuned spars".

A trial design was prepared, but thin-wall aluminum tube for the spar could not be purchased in the desired standard size. The design was re-evaluated for a twenty foot spar constructed of six inch, schedule 40, ABS plastic pipe. The plastic material has the advantage that the spar can be built and taken to sea in two easily handled ten foot sections. Coupling the sections prior to deployment is simple, requiring only ordinary hand tools and cement.

The two sections of the spar are filled with closed-cell polyurethane foam (2 lb/ft^3 density). The foam, adding only 3.6 kg to the total mass, reinforces and stiffens the ABS pipe so that it is more resistant to damage. More important, small cracks or punctures cannot flood the buoy catastrophically.

A sixteen inch O.D. "drum" covers the bottom three feet of the spar. It is cast from a light weight syntactic foam (23 lb/ft^3 density) in a mold formed of 1/16 m fiberglass sheet (0.25 lb/ft^2 area density). This mold forms a permanent reinforcing "skin" for the drum. The proportions of the spar and drum combine to give a tuned period for null heave response of 4.5 seconds, based on the following equation.

$$f = \frac{1}{2\pi}\sqrt{-\left(\frac{g}{L}\right)\ln\left(1-\frac{s}{d}\right)^2} \quad ,$$

where f = tuned frequency, cps,

g = gravity, 32.2 ft/sec^2, (9.8 m/sec^2)

L = drum length, 3 ft., (.91 m)

s = spar O.D., 6.625 in., (16.83 cm)

d = drum O.D., 16.125 in. (40.96 cm)

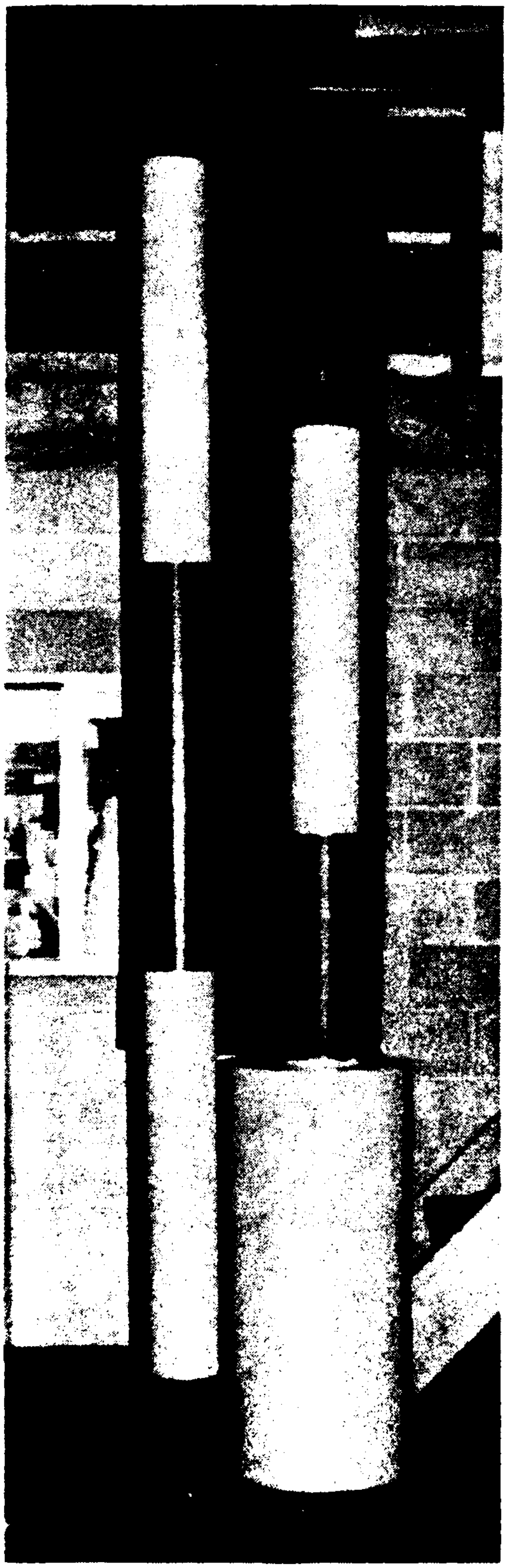

Figure 17. Spar Buoy

The upper spar section has a mass of 38.3 kg (62.4 lbs), including 11.34 kg (25 lb) for the transmitter and its batteries. The lower spar and drum have a mass of 57.69 kg (127.2 lb). Combined, the displacement is 241.7 kg (533 lb) when the spar is submerged. Buoyancy is lost at the rate of 22.6 kg/m (15.3 lb/ft) of freeboard.

The suspended load consists of 1000 m (3,280 ft) of cable having a mass of 93 kg (205 lb) in air and 59 kg (130 lb) in sea water. A 25 kg (55 lb) ballast weight provides 223 N (50 lb) tension at the end of the cable, in sea water. Thus, the reserve buoyancy may be computed as the total displacement less the weight:

$$B_r = 533 = 62.4 - 127.2 - 130 - 50 = 163.4 \text{ lbs } (74 \text{ kg})$$

This yields 3.3 m of freeboard and 2.8 m of draft.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

The analysis, development and testing during this initial phase of the ADAM program has resulted in hardware that will provide an acoustic sensor array that deploys reliably and is compatible with the Air Deployed Oceanographic Mooring.

Using the hardware and equipment that has been developed in the program, it is recommended that:

1. A 1000 m acoustic sensor array be assembled and an open ocean drift test be conducted using the spar buoy as the platform from which the array is suspended.

2. Using the buoys from the ADOM project, fabricate and assemble a complete acoustic system for an over-the-side ship deployment test with data retrieval through the LES-9 Satellite.

SECTION VI

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SECTION VII

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